§13. Satellite line of Xe^{9+} Ions

Mi-Young Song, Kato, T.

Recently EUV light sources from compact plasmas are now intensively studied for the next generation of lithography. The multicharged Xe ions emit EUV emission and are now investigated extensively. However we do not know the detailed atomic processes for there Xe ions. The satelliteline [1-2] transitions for parent emission of the types Xe^{10+} $(4d^7\ 5p^1 \rightarrow 4d^8)$ ion are emitted by the radiative stabilization of doubly excited states in the Xe^{9+} $(4d^7\ 5p^1\ nl \rightarrow 4d^8\ nl)$. The doubly excited states are populated by the processes of dielectronic capture:

$$e + Xe^{10+}(4d^8) \rightarrow Xe^{9+}(4d^7\ 5p^1\ nl) \rightarrow Xe^{9+}(4d^8\ nl) + \hbar\omega \qquad (2)$$

The dielectronic recombination processes is resonated by the incident electron energy, the required being equal to the energy of the doubly excited state relative to the ionzation energy of the Xe^{9+} ion. The autoionization takes place only when the energy of the doubly excited states is above the threshold energy.

The emissivity of a dielectronic satellite transition from the autoionizing state i to a final state f is proportional to a Qd (i_0, i, f) factor which expresses the rate of dielectronic capture into the autoionizing state followed by radiative decay to the final state. Thus, the emissivity of a satellite lines produced by dielectronic recombination can be expressed as

$$I_S = n_e n_Z \left(\frac{h^3}{2\pi m k_B T_e}\right)^{3/2} \frac{e^{-E_{I,I0}/k_B T_e}}{2} \times \langle Qd(i_0)/g_0 \rangle \qquad (3)$$

$$Qd(i_0, i, f) = \frac{g_i Aa(i, i_0) Ar(i \rightarrow f)}{\sum_{all\ i_0'} Aa(i, i_0') + \sum_{all\ f'} Ar(i \rightarrow f')} \qquad (4)$$

where n_e is the electron density, n_Z is the ion density, h is the Plank constant, k_B is the Boltzmann constant, g_i and g_0 are the statistical weights of the autoionizing state (i) formed by dielectronic capture and the target state (i_0) before dielectronic capture, $E_{i,i0}$ is the resonance energy, and $\langle Qd(i_0) / g_0 \rangle$ represent the average value over all initial state the $Xe^{10+}(4d^8)$.

To understand the relation of the satellite lines and the radiative decay lines of Xe^{10+} ions, we need to calculation of the emissivity of a lines produced by collisional excitation rate coefficient from level i_0 to level i' using the Mewe empirical formula based on the Bethe approximation of parent ions can be expressed as

$$I_S = n_e n_Z C_{i_0,i}(T_e) \qquad (5)$$

$$C_{i_0,i}(T_e) = 3.69 \times 10^{-12} \frac{1}{\sqrt{T_e}} \frac{1}{E_{i_0,i}^3} P(E_{i_0,i}/T_e) e^{-E_{i_0,i}/T_e} \times \langle Ar_{i',i_0}\, g_{i'} / g_0 \rangle \qquad (6)$$

where $g_{i'}$ and g_0 are the statistical weights of the excited state i' and ground states i_0 of Xe^{10+} , $E_{i',i0}$ is is the energy difference between i_0 level to i' level and $\langle Ar_{i',i0} * g_{i'} /g_0 \rangle$ represent the average value over all initial state the Xe^{10+} $(4d^8)$. Figure 1 shows the sum of the intensity factor ($\langle Qd(i_0)/g_0 \rangle$) for the satellite transitions from states of the $4d^7\ 5p^1\ 5l$ to $4d^8\ 5l$ of the Xe^{9+} ions about different l, at n=5. Figure 2 shows the $\langle Ar_{i',i0} * g_{i'} /g_0 \rangle$ values of the line from radiative decay from Xe^{10+} $(4d^7\ 5p^1)$ to Xe^{10+} $(4d^8)$.

Through figures, we know that the dielectronic satellite lines of Xe^{9+} ions appear near the radiative decay lines of Xe^{10+} ions and the dielectronic satellite lines have values that can not ignore at low temperate. For identification of the spectrum from the highly charged ions, we will study more detailed about the direct excitation of the parent ions.

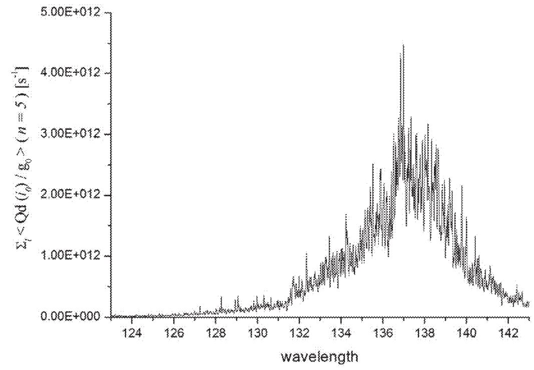

Fig. 1. Satellite line of the transition [$Xe^{9+}(4d^7\ 5p^1\ nl) \rightarrow Xe^{9+}(4d^8\ nl) + \hbar\omega$]

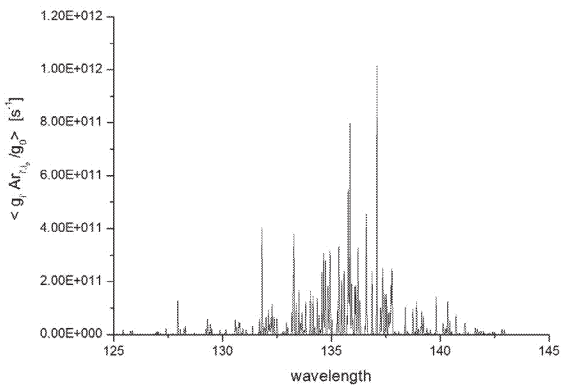

Fig. 2. Radiative line of the transition [$Xe^{10+}(4d^7 5p^1) \rightarrow Xe^{10+}(4d^8) + \hbar\omega$]

Reference

1) R. D. Cowan, "The Theory of Atomic Structure and Spectra", (University of California Press, Berkeley 1981)

2) H. R. Griem, "Principles of Plamsa Spectroscopy" (Cambridge University Press, New York, 1997)